NATIONAL BUREAU OF STANDARDS REPORT

5715

OPERATING CHARACTERISTICS OF A PROTOTYPE MULTI-LAYER CLOTH AIR FILTER FOR ARMY AIRCRAFT

by

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and
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Report to
Aviation Division
Transportation Research and Engineering Command
Fort Eustis, Virginia

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ABSTRACT

Earlier investigations indicated that heavily-napped cloth fabrics have promising characteristics as media for air filters, having high efficiency and moderate pressure drop. As a part of the development program on better air cleaners for helicopters and small aircraft being conducted for the Transportation Research and Engineering Command of the U. S. Army, a prototype multi-layer dry cloth air filter was designed and tested. Two specimens were furnished for flight testing. Tests of an experimental model and one of the prototypes composed of four layers of an Orlon fleece revealed that in excess of 99 percent of the dust in an air stream could be removed under velocity and pressure drop conditions compatible with the requirements of the H-13 and H-23 model helicopters. Although a dust load of 200 to 400 grams of the standard AC Spark Plug Co. test dusts, fine and coarse, used for the tests, increased the pressure drop of the filter from an initial value of 1 to 2 in. W.G. to a final value in the range from 4 to 9 in. W.G., it is probable that a dust load in excess of 2 lb can be accommodated on most airfields because analyses show that the average particle size is larger under actual operating conditions than for the test dusts. The complete prototype filter weighs 3 lb. The cloth media can be readily cleaned and re-used many times and are not adversely affected by being wetted with water.

Introduction

By request of the Aviation Division, Transportation Research and Engineering Command, the development of an oil-bath air cleaner was discontinued in order to complete the development and testing of a prototype dry cloth air cleaner for use on the H-13 and H-23 helicopters. It was indicated that support for this investigation would be terminated at the close of calendar year 1957.

Two specimens of the prototype dry cloth air filter have already been furnished to the Transportation Research and Engineering Command for flight testing. The design of these air filters and the performance of a third specimen in the laboratory are described in this report together with the development work done on a preliminary experimental model.

This report completed the investigation of air cleaners and air cleaning methods by the National Bureau of Standards for the Transportation Research and Engineering Command.

Development of an Experimental Multi-Layer Dry Cloth Air Cleaner

Earlier investigations of a number of fabrics indicated that heavily-napped cloth showed promising characteristics as a medium for air cleaners. However, the filtering efficiency of all single layer fabrics which had a reasonable dust holding capacity was lower than desired and the air velocities through the media had to be kept so low that the physical dimensions of a single layer air cleaner exceeded those practicable for aircraft application. The results of these tests were shown in the Progress Report for calendar year 1956, pages 16 and 17.

For determining the performance of multiple layers of cloth an experimental air cleaner was designed and constructed. A photograph of this experimental air cleaner is shown in fig. 1. It consisted of a plywood box, the upper part of which was detachable and had a metal hood as an air intake. Three deep triangular notches were cut in the front and rear walls of the upper part of the box to match corresponding notches in the lower portion of the box, leaving a quarter-inch space between matching edges. The lower part was

Fig. 1

equipped with an adapter to connect it to the air duct leading to the exhaust blower. A 16-mesh wire screen was installed in the lower notched section to support the fabric that was pleated along the cut-outs and clamped between the two halves when the box was closed. The free area of cloth was two sq ft and the angle of the pleats was 20°. The important feature of this apparatus was that it permitted determination of the amount of dust retained in each of several layers of filter cloth by measuring the weight increase caused by the introduction of a known weight of dust during each test.

Filters consisting of two to five layers of fabric were investigated. In some cases all layers were of the same fabric, in others different fabrics were used together, whereas in still other tests the backing of some layers was installed facing towards the air inlet. These tests indicated that, in most combinations, more than 60 percent of all dust was retained by the first layer which resulted in a more rapid increase in pressure drop for this layer. Many kinds of fabrics were tested trying to obtain a more nearly equal deposit of dust on the various cloth layers. But it was determined that any combination of materials that would produce approximately equal dust accumulations on two or more layers with one of the test dusts would not perform the same with the other one. Since the difference in size of the dusts from different air fields was found to be much greater than the difference between the AC Spark Plug dusts "fine" and "coarse" used in these tests, it was felt that it would not be possible to find any combination of fabrics which would retain on several successive layers equal amounts of dust over as wide a range of particle sizes as would be expected to occur during actual use of the air cleaner in flight and on the ground. In military application, the use of only one kind of fabric would eliminate the possibility of mixing up the sequence of the several layers, when reassembling the air cleaner after cleaning.

Since Orlon fleece produced the best over-all results of all materials tested, including some experimental fabrics, a series of performance tests was made in which the weight increase of each layer was determined for a dust load of 100g. Table 1 shows the results observed for five different air flow rates ranging from 175 cfm to 300 cfm, corresponding to face velocities ranging from 87.5 ft/min. to 150 ft/min. using AC Spark Plug Co. coarse and fine dusts and a mixture of 50 percent each of the two dusts. These dusts had the following particle size distribution by weight.

Table 1

Weight Increase of Individual Layers of Orlon Fleece
in Experimental Air Cleaner

Layer	Air Flow Rate, CFM 175	200	225	250	300
			Coarse Dust		
1	86.01	76.94	76.38	73.65	73.45
2	12.13	18.62	18.30	20.04	19.09
3	1.64	3.44	3.91	4.72	5.61
4	0.07	0.41	0.74	1.31	1.65
Total	99.95	99.41	99.33	99.72	99.80
			50% Coarse and 50% Fine		
1	92.46	91.13	89.52	88.71	88.62
2	4.69	6.84	8.20	9.03	8.83
3	1.73	1.27	1.24	1.46	1.38
4	00.73	0.60	0.68	0.58	0.50
Total	99.61	99.44	99.64	99.78	98.93
			Fine Dust		
1	92.97	93.10	92.43	91.75	90.15
2	3.81	4.11	4.38	5.38	6.20
3	1.21	1.07	0.98	1.11	1.24
4	0.55	0.57	0.57	0.52	0.49
Total	98.54	98.85	98.36	98.76	98.08

Size Range	Coarse	50/50	Fine
0-5 microns	12±2%	25.5±2%	39±2%
5-10 "	12±3%	15±3 %	18±3%
10-20 "	14±3%	15±3 %	18±3%
20-40 "	23±3%	20.5±3%	18±3%
40-80 "	30±3%	19.5±3%	9±3%
80-200 "	9±3%	4.5±3%	--

It will be noted in Table 1 that the amount of dust retained on the first layers decreased with increasing air velocity and also with increasing fineness of the dust. The weight gain of the second layers increased appreciably with an air flow rate up to 250 cfm and decreased slightly at 300 cfm air flow during the tests with coarse and 50/50 dust but kept on increasing when fine dust was used. The gain of the third and fourth layers increased with increasing air velocity only when coarse dust was used but was very little affected by the air velocity with finer dusts.

The fact that the weight increase of the first layers represented up to 93 percent of the total fine dust introduced explains the fact that the pressure loss increased more with fine dust than with coarse dust where a maximum of 86 percent was retained in the first layers. The total amount of dust collected on the four layers of cloth from 100g of dust introduced into the air cleaner was very close to the efficiency values observed on this experimental model by means of the sampling method. Since the effect of dust load and air velocity on efficiency and pressure loss are shown later for the prototype model, they are omitted here for the experimental model.

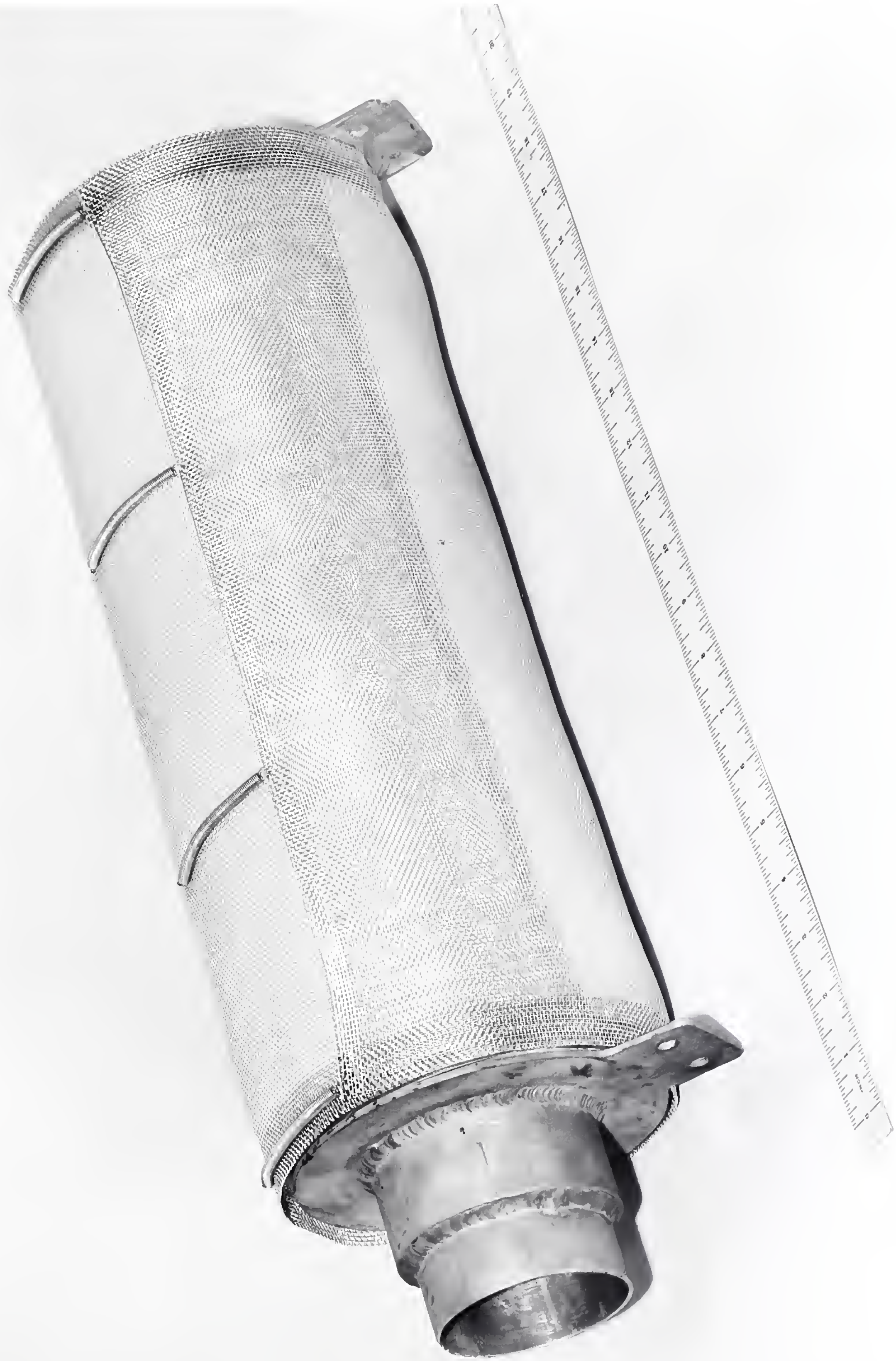
A microscopic examination of the dust particles that had passed through the filter media of the experimental model at 200 cfm air flow rate showed very little difference in size distribution regardless of which of the three test dusts had been used. Some particles up to 80 microns in diameter were found to have passed through the filter media when coarse and mixed coarse-and-fine dusts were used. The largest size particles in the samples taken downstream of the filter when fine dust was used were about 50 microns in diameter. There

were few particles in any sample below 25-micron and above 50-micron size. This appears to indicate that the small dust particles adhered to the fibers of the fabric whereas all particles larger than 80 microns and most of those larger than 50 microns were retained by the backing of the cloth.

Design and Performance of a Prototype Dry Cloth Air Cleaner for Helicopters

The results observed with the experimental model indicated that the over-all characteristics of an air cleaner with four layers of Orlon fleece should meet nearly all the requirements of size, weight, efficiency and pressure drop set forth at the beginning of the project. A prototype air cleaner of this type was, therefore, designed and constructed of light weight metal in which one piece of fabric was wrapped continuously in four layers around a cylindrical screen. Fig. 2 shows the prototype assembled and fig. 3 is a view of the component parts. In the latter photograph the core with the heavy aluminum screen cylinder welded between two flanges is at the upper left. The flanges are used to support the air cleaner in the aircraft. One of the flanges is closed and the other one is fitted with a two-step adapter which can be connected to either 3-in. I.D. or 4-in. I.D. air intake hoses. The Orlon fleece, wrapped around this core, is held on each end with a stainless steel clamp, and a 16-mesh aluminum window screen protects the fabric from excessive erosion due to wind. The screen is held by four small coil springs. The over-all length of the air cleaner is 20 in., the diameter 6 in., and its weight is 3 lb, 1 oz (1,400g).

Inasmuch as the maximum air requirement of the engines used on the H-13 and H-23 helicopters will not exceed 230 cfm, the performance tests of this prototype air cleaner were conducted at 250 cfm, 200 cfm and 150 cfm, the latter being the approximate air requirement at idling speed. For testing purposes, the air cleaner was mounted inside a cylindrical container which left a 2-in. annular air space between the outside of the air cleaner and the container. The air was introduced through the top pipe as shown in fig. 4, where the container is shown to the left of the filter itself. This photograph also shows the location of the pressure taps and the upstream sampler holder. The lower flange of the air cleaner was tightly sealed against



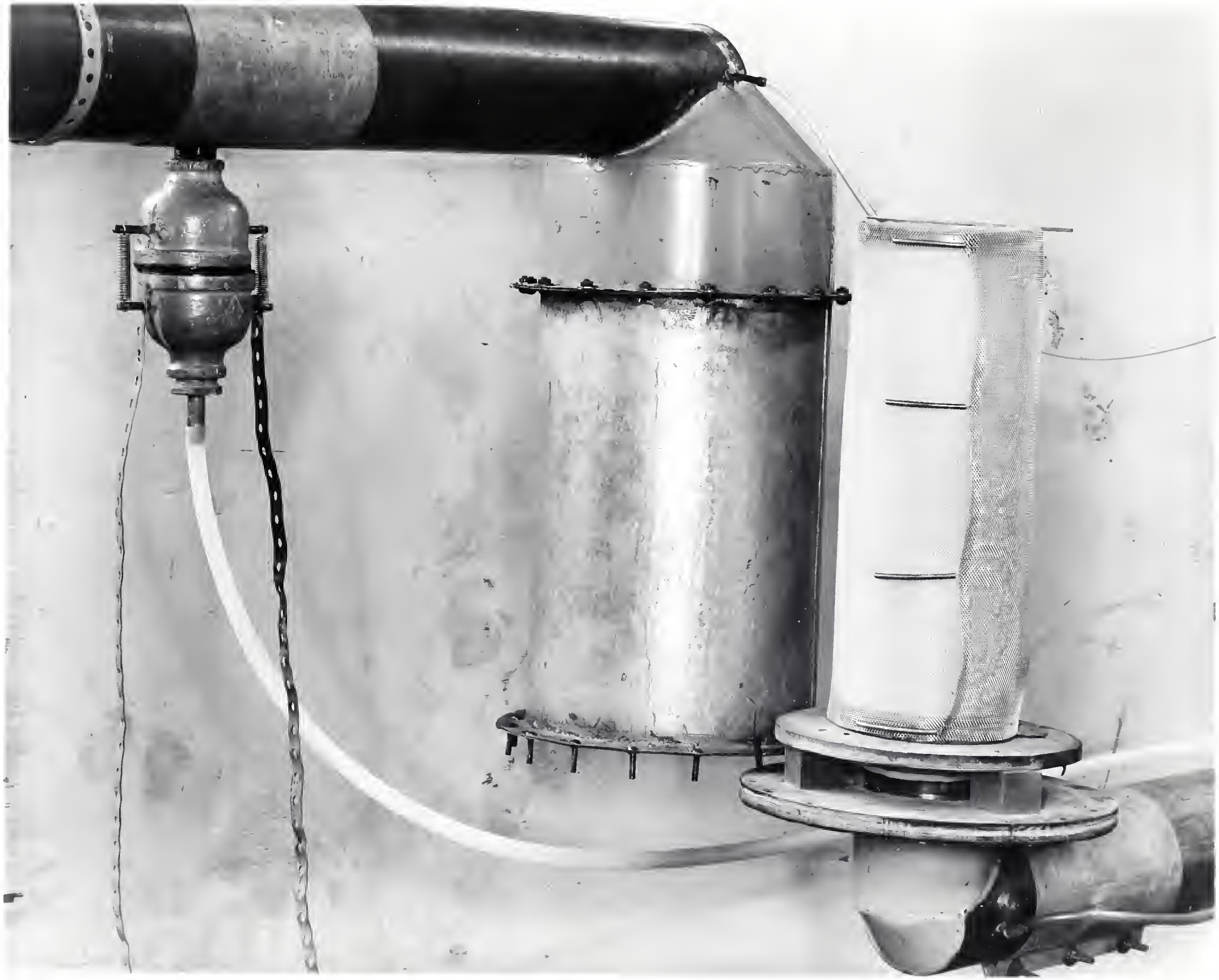


Fig. 4

the bottom plate of the container and the container itself could be closed so that no air could leak into it. All air going through the outlet pipe at the bottom of the container had to come through the duct inlet where the test dust was introduced. A series of tests was conducted at the three air flow rates with classified test dust of three particle size ranges, namely AC Spark Plug Co. dust "coarse," "fine" and a mixture of 50 percent of each.

A dust load of 50g was introduced during each test run and the pressure drop and filtering efficiency were determined with the apparatus described in previous reports. Table 2 shows the values observed for the pressure drop and indicates that the finer the dust, the greater was the increase of pressure loss for an equal amount of dust introduced. This phenomenon had been observed on most of the impingement type air cleaners that have been examined at this laboratory. At an air flow rate of 250 cfm the pressure loss increased from 2.32 in. W.G. with a clean cloth to 8.90 in. W.G. when 200 g of fine dust were introduced, whereas it increased to only 5.31 in. W.G. with 400 g of coarse dust.

Table 2

Pressure Loss of Prototype Cloth Air Filter, in. W.G.

Dust Load, g	250 CFM			200 CFM			150 CFM		
	C	50/50	F	C	50/50	F	C	50/50	F
0	2.32	2.32	2.32	1.54	1.54	1.54	1.14	1.14	1.14
50	2.44	2.75	3.07	1.73	1.93	2.16	1.18	1.34	1.58
100	2.60	3.34	4.37	1.93	2.52	3.30	1.34	1.77	2.68
150	2.72	4.33	6.50	2.17	3.58	4.92	1.61	2.52	4.25
200	2.98	5.70	8.90	2.52	4.92	7.01	2.01	3.58	6.50
250	3.35	7.37		3.03	6.62		2.60	5.04	9.42
300	3.86			3.58			3.19	6.70	
350	4.53						3.78	8.86	
400	5.31								

Table 3

Efficiency of Prototype Cloth Air Filter, Percent

Dust Load, g	250 CFM C	250 CFM 50/50	250 CFM F	200 CFM C	200 CFM 50/50	200 CFM F	150 CFM C	150 CFM 50/50	150 CFM F
50	99.7	98.7	98.4	99.8	98.8	98.1	99.6	98.9	97.1
100	99.6	99.2	99.1	99.8	99.4	99.1	99.7	99.2	99.0
150	99.8	99.4	99.6	99.7	99.5	99.5	99.7	99.6	99.4
200	99.8	99.6	99.6	99.6	99.6	99.6	99.8	99.6	99.5
250	99.8	99.5		99.5	99.8		99.9	99.7	99.6
300	99.6			99.4			99.8	99.7	
350	99.6						99.8	99.7	
400	99.5								
Average	99.7	99.3	99.2	99.6	99.4	99.1	99.8	99.5	98.9

A summary of the efficiencies determined from these tests is contained in Table 3. The average efficiencies were above 99 percent except for the series of tests with fine dust at an air flow rate of 150 cfm. The lowest value observed for a single test was 97.1 percent for the first 50 g of fine dust introduced into a clean air cleaner at 150 cfm. The data in Tables 2 and 3 are shown graphically in fig. 5 and 6, respectively.

No change in the efficiency or pressure loss could be observed when certain tests made with a new cloth were repeated after the cloth had been cleaned more than twenty times and also had been soaked with water and dried several times.

Conclusions

It has been determined from dust analyses made of dusts from numerous air fields that the classified test dusts used in these tests have a much smaller mean particle size than the dust that will probably be accumulated in an air cleaner during actual operation. Therefore, it is estimated that during usage of this type air cleaner on typical air fields, a pressure loss of 8 in. W.G. will not occur until the dust load is in excess of 2 lb. It is also probable that a portion of the dust accumulating on the outside layer of cloth will be blown off by the down-wash of the rotor. The

Pressure Drop versus Dust Load of the Prototype Cloth
Air Filter at Three Air Flow Rates

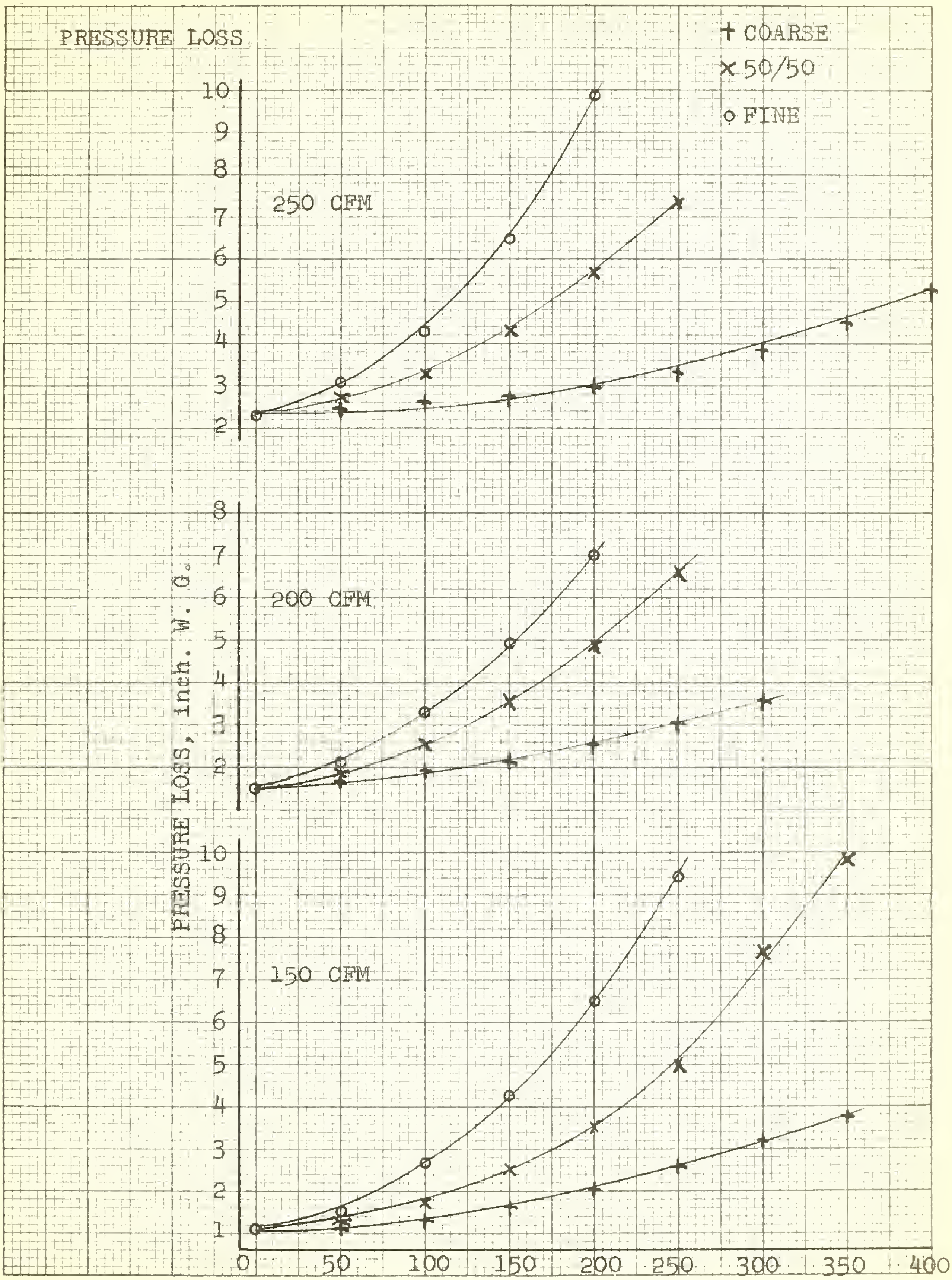


Fig. 5

Efficiency versus Dust Load of the Prototype Cloth Air Filter at Three Air Flow Rates

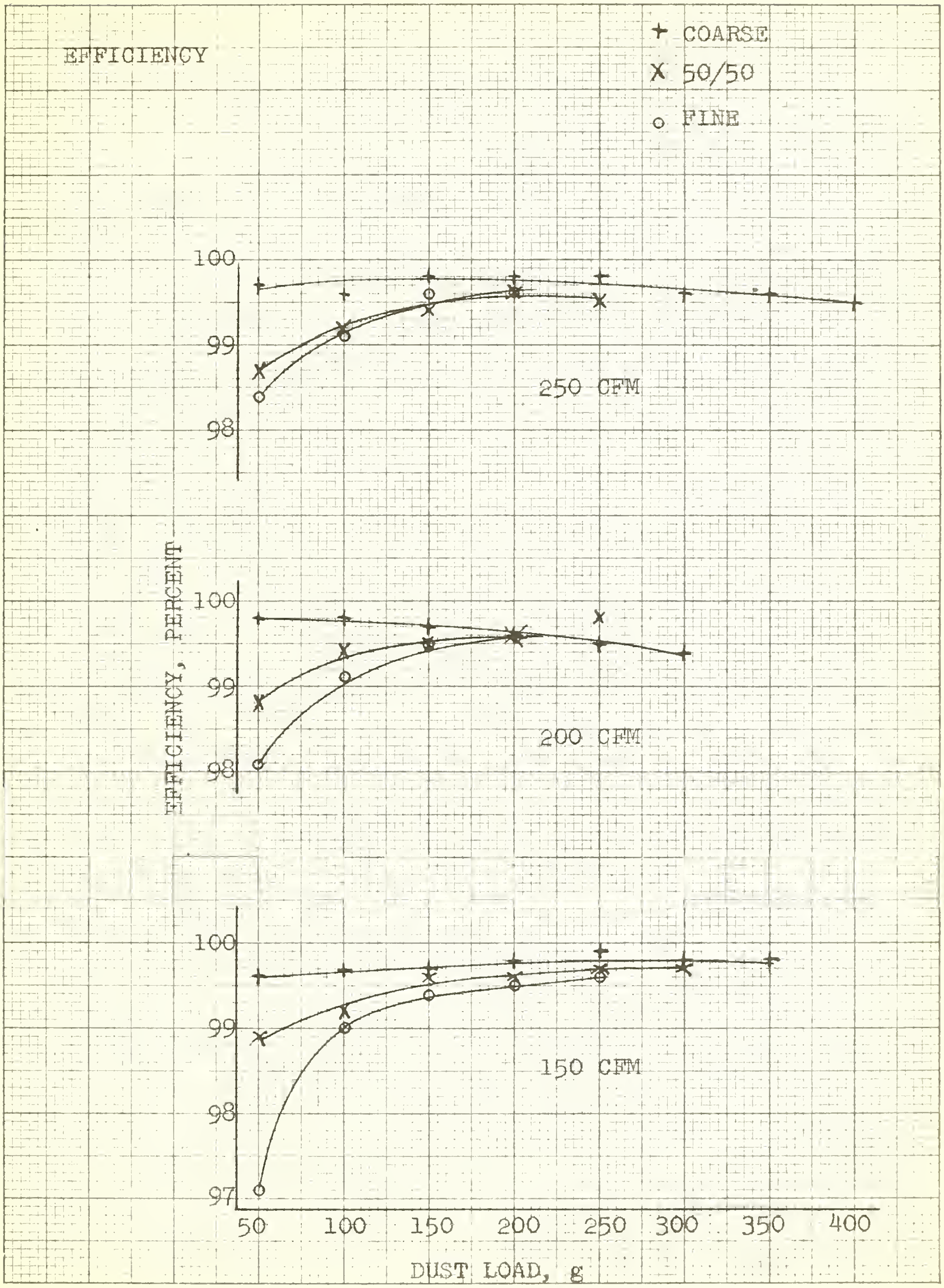


Fig. 6

cleaning of the prototype air cleaner requires no special equipment; the cloth is taken off and the dust can be shaken out. No replacement of the Orlon fleece nor any other component of this air cleaner will be required under ordinary circumstances. The weight of the complete cleaner of 3 lb 1 oz compares favorably with that of any other air cleaner plus its enclosure, and its filtering efficiency at least equals that of any other air cleaner tested in this laboratory.

It is, therefore, recommended that appropriate flight tests be made with this prototype multi-layer dry cloth air cleaner.

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